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A NOVEL NONCONTACTING WAVEGUIDE BACKSHORT FOR MILLIMETER AND SUBMILLIMETER WAVE FREQUENCIES

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ABSTRACT

A new noncontacting waveguide backshort has been developed for millimeter and submillimeter wave frequencies. It employs a metallic bar with rectangular or circular holes. The size and spacing of the holes are adjusted to provide a periodic variation of the guide impedance on the correct length scale to give a large reflection of rf power. This design is mechanically rugged and can be easily fabricated for frequencies from 1 GHz to 1000 GHz. This design is particularly useful for submillimeter wave frequencies above 300 GHz where conventional backshorts are difficult to fabricate. Model experiments have been performed at 4-6 GHz to optimize the design. Values of reflected power greater than 95% over a 30% bandwidth have been achieved. The design has been scaled to WR-10 band (75-110 GHz) with comparably good results.

INTRODUCTION

Waveguides are used in a wide variety of applications covering a frequency range from 1 GHz to over 600 GHz. These applications include radar, communications systems, microwave test equipment, and remote-sensing radiometers for atmospheric and astrophysical studies. Components made from waveguides include transmission lines, directional couplers, phase shifters, antennas, and heterodyne mixers, to name a few. In addition to the many commercial applications of waveguides, NASA needs such components in radiometers operating up to 1200 GHz for future space missions, and the Department of Defense is interested in submillimeter wave communications systems for frequencies near 1000 GHz.

One of the most frequent uses of waveguide is as a variable length transmission line. These lines are used as tuning elements in more complex circuits. Such a line is formed by a movable short circuit or "backshort" in the waveguide. A conventional approach is to use a contacting backshort where a springy metallic material, such as beryllium copper, makes DC contact with the broadwalls of the waveguide. The contacting area is critical, however, and must make good contact to produce an acceptable short circuit. These backshorts are excellent in that they provide a good short circuit over the entire waveguide band. However, the contacting areas can degrade from sliding friction and wear. It is also extremely difficult to get a uniform contact at frequencies above 300 GHz where the waveguide dimensions become 0.5 mm × 0.25 mm for the 300-600 GHz band.

An alternative solution is the noncontacting backshort shown in Fig. 1. A thin mylar insulator prevents contact and allows the backshort to slide smoothly. In order to produce an rf short circuit and, hence, a large reflection, this backshort has a series of high- and low-impedance sections which are approximately $\lambda g/4$ in length where λg is the guide wavelength. The rf impedance of this design is given approximately by

$$Z_{rf} = \left(\frac{Z_{low}}{Z_{high}}\right)^n Z_{low} \tag{1}$$

where Z_{low} is the guide impedance of the thick (low-impedance) section; Z_{high} is the impedance of the thin (high-impedance) section; and n is the number of sections. Values of $Z_{rf} < 1$ ohm are theoretically possible which provides a good short circuit. However, beginning near 100 GHz, the thin high-impedance section become difficult to readily fabricate, and in the 300-600 GHz band, these sections become too thin to fabricate. The backshort is no longer strong enough to slide snugly in the waveguide.

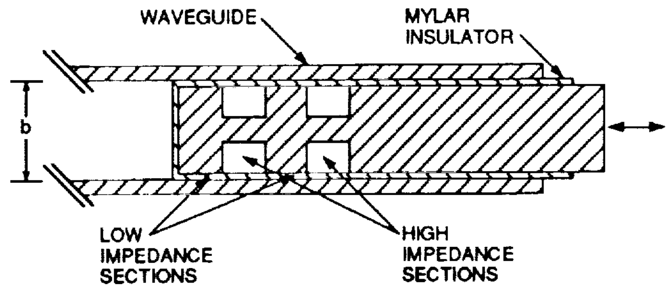

Figure 1. **Cross sectional view of a conventional noncontacting backshort. "b" is the waveguide height.**

New Backshort Design

A new noncontacting backshort has been developed and is shown in Fig. 2. In order to obtain a large reflection, a noncontacting backshort must provide a periodic variation of guide impedance on the correct length scale. This is accomplished in the new design by either rectangular or circular holes with the proper dimensions and spacing cut into a metallic bar. This bar is dimensioned to form a snug fit in the waveguide with a mylar insulator along the broadwalls. The holes replace the thin-metal, high-impedance sections in the conventional design shown in Fig. 1. Since the holes extend completely through the bar, this yields a

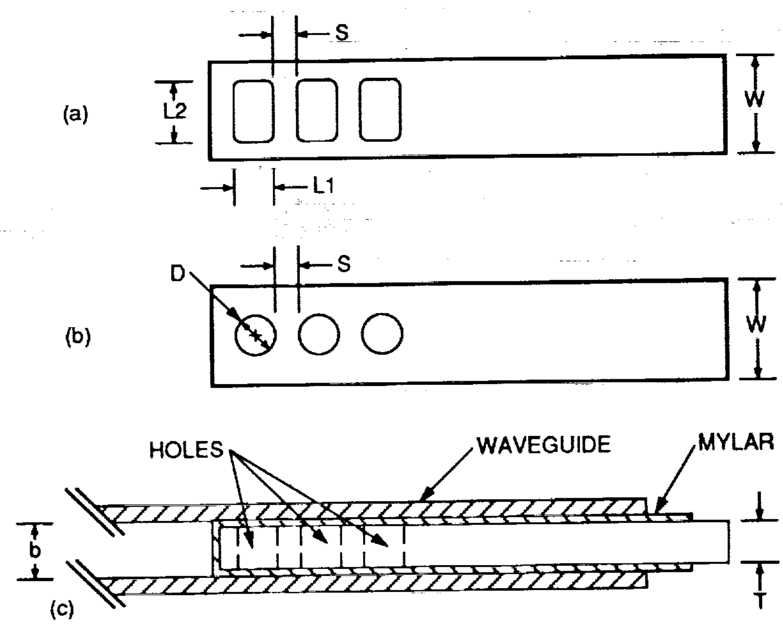

Figure 2. **New noncontacting backshort design. (a) A metallic bar of width W and thickness T with rectangular holes cut near one end. The hole length L_1 and separation S are important in determining the rf properties. "S" is also the distance from the end of the bar to the edge of the first hole. (b) A similar backshort design using round holes. (c) Cross sectional view of the new backshort design in the waveguide. A thin mylar insulator allows the backshort to slide smoothly.**

higher impedance than the corresponding sections in the conventional design. Thus, the high-to-low impedance ratio is larger in the new design. In addition, the electromagnetic fields and power are concentrated near the central axis of the waveguide, so the holes are effective in producing correlated reflections leading to an overall large reflection of rf power. The new design is also easy to fabricate and can be used at any waveguide frequency between 1 GHz and 1000 GHz. For very high frequencies, above 300 GHz, the metallic bar is a piece of shim stock polished to the correct thickness. The holes can be formed by drilling, punching, laser machining, or can be etched using common lithography techniques.

Measurement Techniques

The backshort design was optimized by testing the performance in WR-187 band waveguide (3.16 GHz - 6.32 GHz). The waveguide dimensions are 47.5 mm x 22.1 mm (1.87 in x 0.87 in). The magnitude and phase of the reflection coefficient were measured with an HP 8510B Vector Network Analyzer. A commercially available coaxial-to-waveguide transition was used to connect the waveguide to the network analyzer. This measurement system was calibrated using two offset contacting shorts set at $\lambda g/8$ and $3\lambda g/8$ in the waveguide and a sliding waveguide load. Subsequent verification using a contacting short indicated a measurement error of about ± 0.2 dB in the magnitude measurement.

Several WR-187 band backshorts were built and tested. The varied parameters were the (a) shape of the holes, (b) size of the holes, (c) spacing of the holes, (d) number of holes, (e) thickness, T, of the backshorts and, hence, width of the gap between the backshort and the waveguide wall, and (f) thickness of the mylar insulator. Each of these parameters can affect the electrical length of the high- and low-impedance sections which determines the performance of the backshort.

Millimeter wave tests were also made in WR-10 waveguide at 75-110 GHz. The test apparatus is shown in Fig. 3. A Micro-Now backward wave oscillator (BWO) and Singer sweeper were used to provide a 75-110 GHz swept signal. A direct detector, 10 dB directional coupler, and Wiltron 560A Scalar Network Analyzer were used to detect the reflected power. The system was calibrated by placing a copper plate at the position of the reference plane at the waveguide flange.

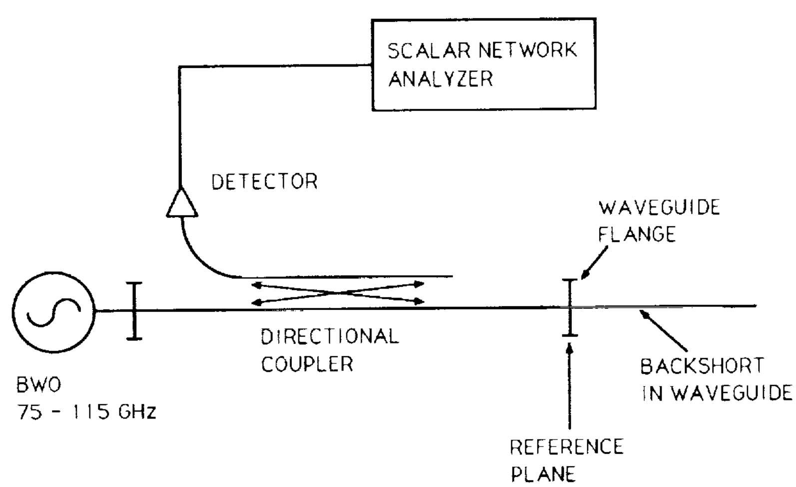

Figure 3. Millimeter wave test apparatus.

RESULTS

WR-187 Band Measurements

Figure 4 shows the reflected signal for a solid bar without holes. This backshort has dimensions W = 47.5 mm and T = 19.7 mm. This leaves a gap of 1.2 mm on either side of the bar and waveguide wall. This is a large gap, but it corresponds to typical machining tolerances to be expected for much smaller waveguides at 200-300 GHz. The mylar is 0.89 mm thick (the mylar thicknesses used for the various backshort tests were obtained by stacking two to five layers of 0.127 mm and 0.254 mm thick sheets). As seen in Fig. 4, the solid bar without holes does not make a good backshort. There are several frequency bands where the reflection is much less than -1.0 dB (0.79 reflected power). A mode is readily generated in the mylar-filled gap between the bar and the waveguide wall, and the power escapes out the end of the waveguide. At a few frequencies, the reflection coefficient approaches -0.25 dB but only over a very narrow bandwidth.

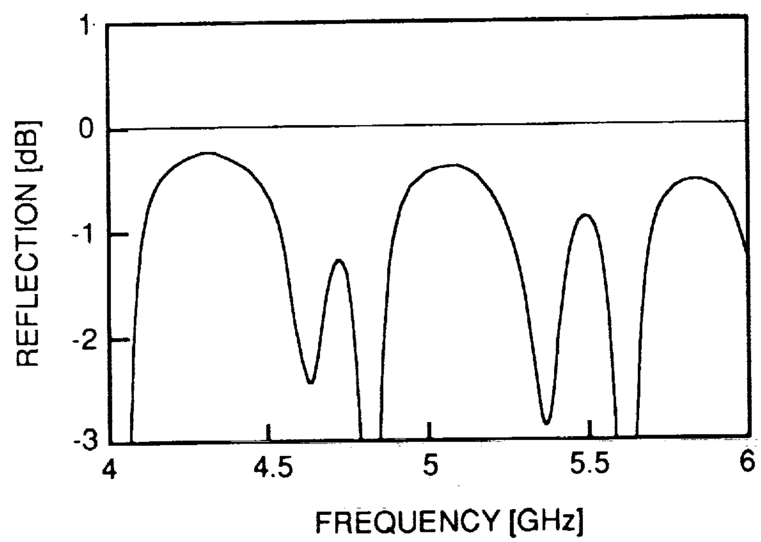

Figure 4. Reflected Power from a solid bar without holes. This design does not make a good backshort. Several large dropouts occur across the frequency band.

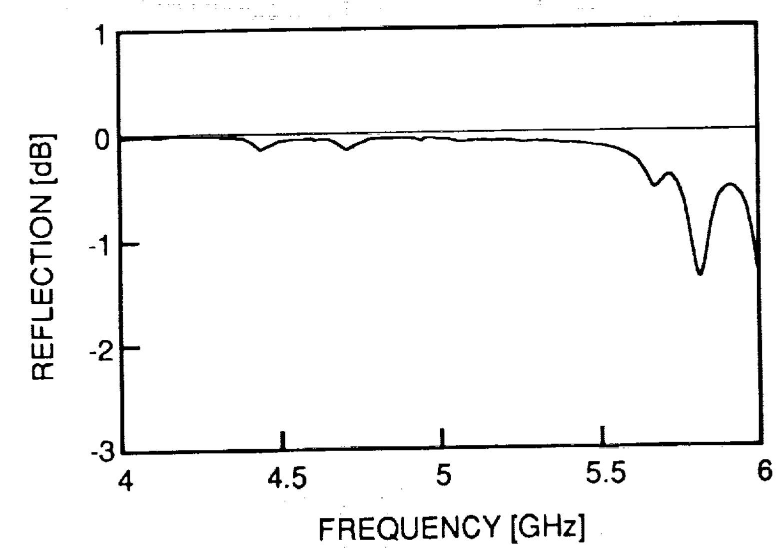

Figure 5. Reflected power from a backshort with three rectangular holes. The mylar is 0.89 mm thick. Excellent performance is obtained over a broad bandwidth.

Figure 5 shows the reflected signal for a bar with rectangular holes. The reflection coefficient is greater than -0.2 dB (0.95 reflected power) over a 33% bandwidth centered around 4.8 GHz. This is, of course, a dramatic improvement over the solid bar without holes. The backshort dimensions are W = 47.5 mm x T = 19.7 mm, and the mylar thickness is 0.89 mm. There are three holes, each with dimensions L_1 = 19.3 mm, L_2 = 28.4 mm and spacing S = 8.7 mm. Taking the center frequency of the stop band to be 4.8 GHz implies that the high-impedance section lengths are L_1 = 0.24 λg where λg = 79.1 mm, and the low-impedance sections are S = 0.17 λg where λg = 50.3 mm. The presence of the mylar modifies the waveguide modes. The guide wavelengths, λg, for the high- and low-impedance sections were calculated using a transverse mode technique which is described in references [1] and [2]. We are currently working on a full theoretical description which will allow one to calculate and design the center frequency, bandwidth, and reflection coefficient as a function of hole size, shape, spacing, and dielectric thickness [3].

A significant decrease in the reflection coefficient (a "dropout") is seen near 5.8 GHz in Fig. 5. The position of this dropout was dependent on mylar thickness. Increasing the mylar thickness, which decreases the guide wavelength, moved the dropout to lower frequency. Decreasing the thickness moved it to higher frequency. Figure 6 shows the result for a mylar thickness of 0.64 mm. The response is much flatter except for a slight decrease in reflection near 4.8 GHz. This response is comparable to that obtained for the conventional type of backshort shown in Fig. 1.

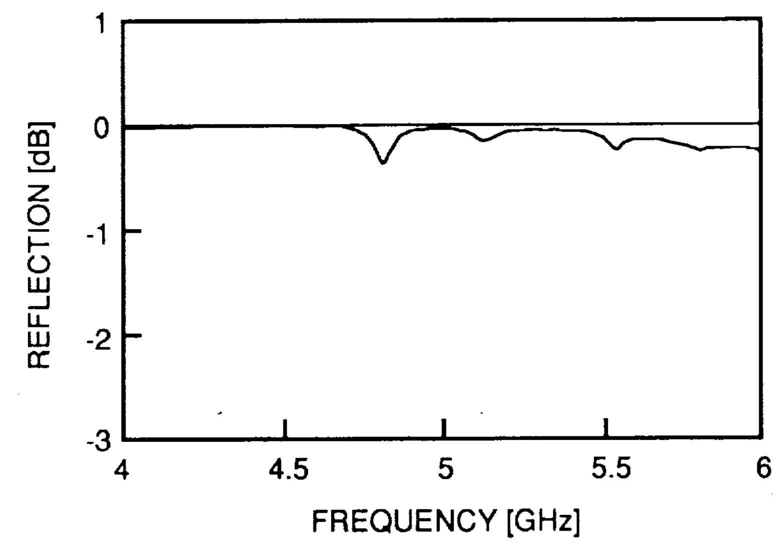

Figure 6. Reflected power from a backshort with three rectangular holes. Reducing the mylar thickness to 0.64 mm moved the dropout seen in Fig. 5 out of band. The performance is comparable to a conventional noncontacting backshort.

Figure 7 shows the reflection coefficient for a backshort with three circular holes of diameter D = 19.3 mm and spacing S = 8.7 mm. The bar dimensions are W = 47.5 mm x T = 19.7 mm, and the mylar thickness is 0.89 mm. The reflection is greater than 0.2 dB over a 32% bandwidth with a center frequency near 4.75 GHz. This gives the high-impedance section lengths D = 0.24 λg where λg = 80.6 mm, and the low-impedance section lengths S = 0.17 λg where λg = 51 mm [1, 2]. These results are similar to those obtained with the rectangular holes. This is encouraging since round holes are easier to fabricate. The dropout near 5.7 GHz is somewhat larger than that seen in Fig. 5. This probably results, in part, from power which leaks around the edges of the holes. Deceasing the mylar thickness to 0.64 mm moves the dropout to high frequency. The result is shown in Fig. 8. A new dropout, however, is beginning to appear at the low frequency end.

Many other variations of the backshort parameters, other than those discussed here, were tested. These variations affected the magnitude, phase, and bandwidth of the rf reflection. A more extensive discussion of these systematic variations will be given at a later date. The results discussed here are typical of the best performance to date.

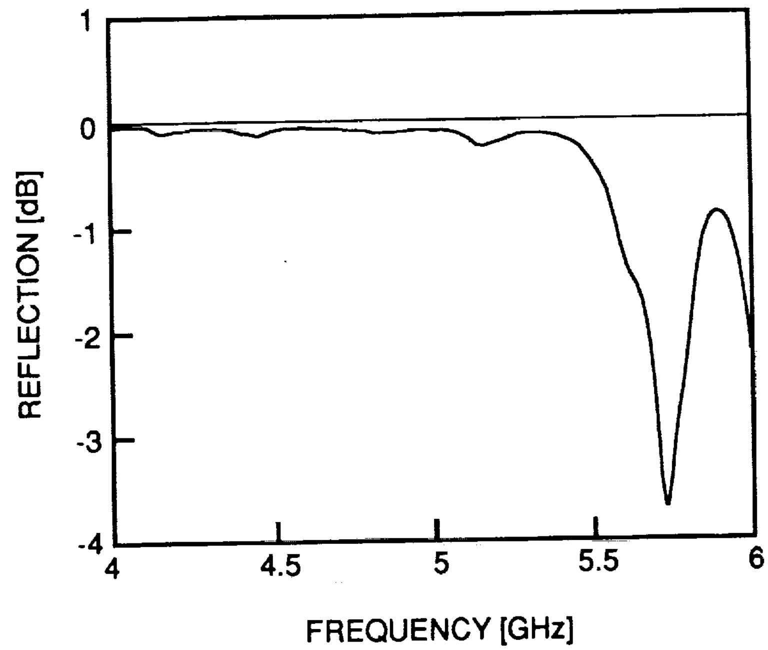

Figure 7. **Reflected power for a backshort with three round holes. The mylar thickness is 0.89 mm. The performance is comparable to the backshort with rectangular holes.**

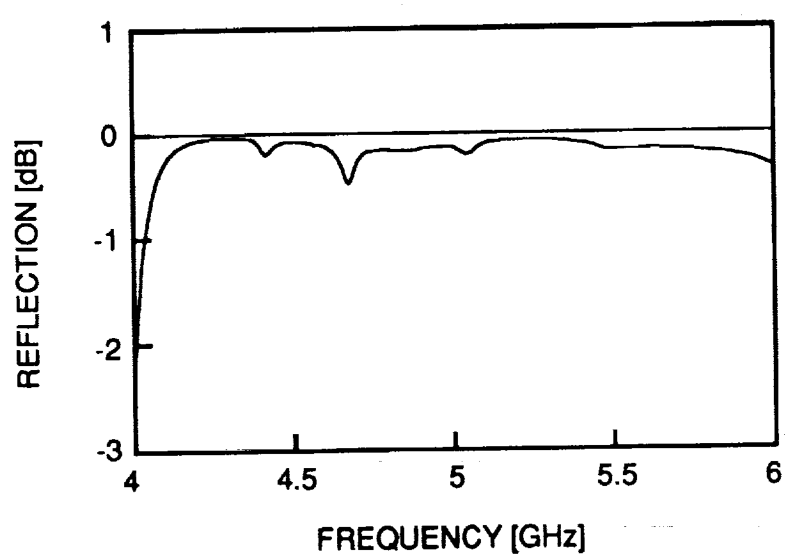

Figure 8. **Same backshort as in Fig. 7, except mylar thickness is reduced to 0.64 mm. The dropout at the high-frequency end has moved out of band.**

WR-10 Band Measurements

A crucial test of this new design is to measure its performance at millimeter wave frequencies. The WR-187 band backshorts were scaled for use at WR-10 band. The scale factor is 0.0535. Thus, the backshort dimensions are W = 2.54 mm × T = 1.05 mm. The WR-10 waveguide dimensions are 2.54 mm × 1.27 mm (0.10 in × 0.05 in). The frequency range, 4 GHz - 6 GHz, scales up to 75 GHz - 112 GHz.

Figure 9 shows the reflection coefficient versus frequency for a backshort with three rectangular holes. The hole dimensions and spacing were scaled from the low frequency case. The mylar is 0.051 mm thick which corresponds to 0.95 mm at WR-187 band. Thus, the results in Fig. 9 should correspond approximately to those shown in Fig. 5. As seen in Fig. 9, the performance is excellent and corresponds well with the low-frequency case. The decrease in reflection near 110 GHz corresponds almost exactly to the dropout seen near 5.8 GHz. The reflection coefficient is -0.05 dB to -0.3 dB over about a 30% bandwidth. This is suitable for practical applications. The missing sections of the curves in Fig. 9 correspond to frequencies at which the BWO was unstable and the data could not be adequately normalized.

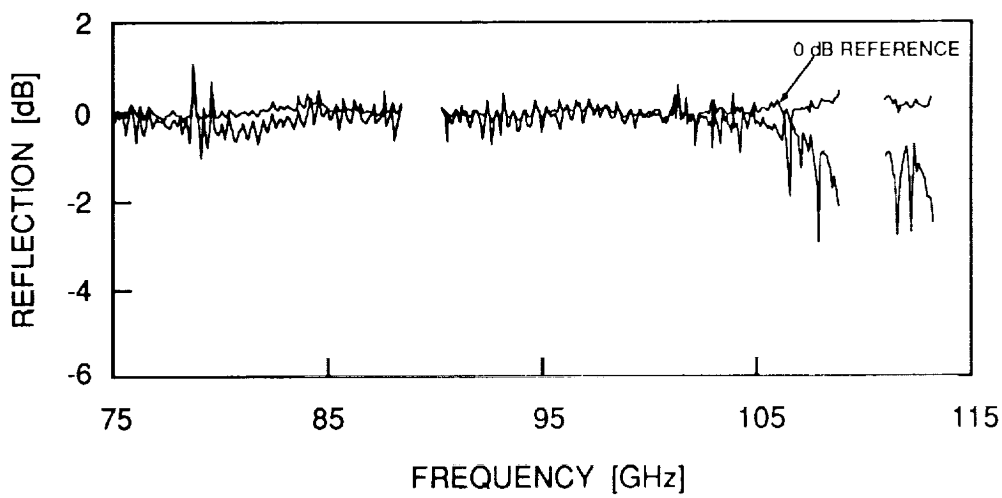

Figure 9. **Reflected power for a backshort with three rectangular holes in WR-10 waveguide. The 0 dB reference is provided by a metal plate inserted between the waveguide flanges. Excellent performance is obtained over a broad bandwidth. This result is comparable to the low-frequency case (see Fig. 5).**

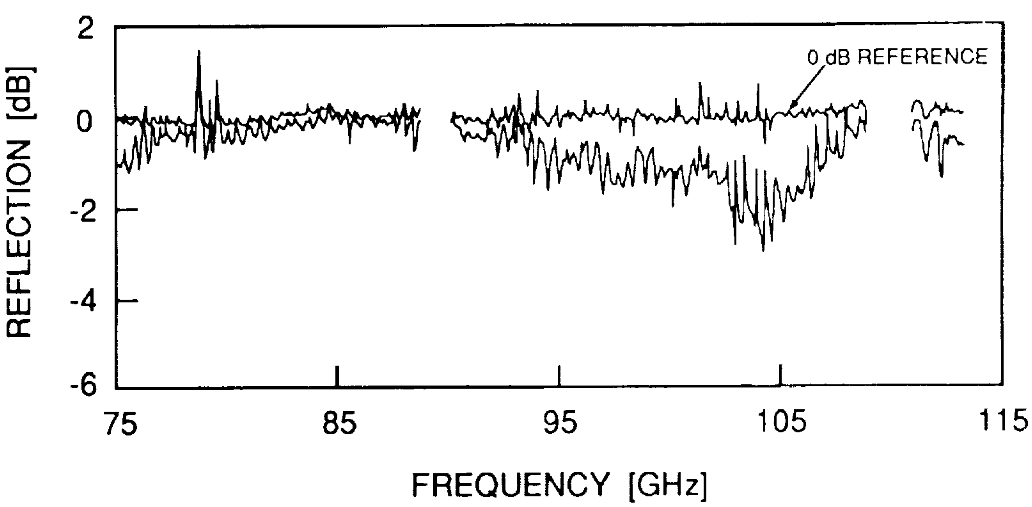

Figure 10. **Reflected power for a backshort with three round holes in WR-10 waveguide. The 0 dB reference is provided by a metal plate inserted between the waveguide flanges. The performance is comparable to the low-frequency case (see Fig. 7), but the bandwidth is narrower.**

Figure 10 shows the performance for a backshort with three round holes. These results correspond to the low-frequency case shown in Fig. 7. The reflection coefficient is -0.3 dB or better over the frequency range from about 76 GHz to 90 GHz. Again, this is well suited for many applications. However, this is only about half the bandwidth observed in the low-frequency case. The dropout near 105 GHz, nonetheless, corresponds well to that seen in Fig. 7. The generally low reflection, ≈ -1 dB, between 90 GHz and 105 GHz, however, is not seen in the low-frequency case. It may simply result from the mylar thickness not being exactly correct. Further tests with the low-frequency backshort are needed to check this as well as sensitivity to other dimensional tolerances.

CONCLUSIONS

A new noncontacting waveguide backshort design has been developed which provides performance as good as the more developed conventional approaches. It employs a metallic bar with rectangular or circular holes to provide a periodic variation of the waveguide impedance on the correct length scale to result in a large reflection of rf power. This design is mechanically rugged and can be easily fabricated using a variety of methods for frequencies from 1 GHz to 1000 GHz. It should allow tunable waveguide systems to be extended well above 300 GHz.

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